CMS CR -2018/088

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

21 June 2018 (v2, 05 August 2021)

Upgraded back-end electronics for the CMS Fast Beam Conditions Monitor

Nicolo Tosi for the CMS Collaboration

Abstract

In the CMS experiment, the Fast Beam Conditions Monitor (BCM1F) detector, located close to the Interaction Point, provides an online, bunch-by-bunch measurement of both Luminosity and Machine Induced Background. The Beam Pickup Transformer (BPTX) provides instead a precise measurement of beam intensity and arrival time. An upgraded back-end electronics has been developed for the BCM1F, based on the modern uTCA standard which has been adopted by several other CMS subsystems. This system, which is slated to replace the current VME-based readout, will also be used to replace the BPTX readout, currently implemented with an oscilloscope-based system. The upgraded back-end is composed of FPGA carrier cards, developed by CERN, coupled to commercial mezzanine cards hosting high-performance digitizers. While the carrier card and most of the FPGA firmware is common, the digitizer and the signal processing algorithm is detector-specific. The main challenge for the BCM1f readout is ensuring the correct identification of all particle hits, even when multiple particles reach the detector in the same bunch crossing. A peak finder algorithm has been developed, capable of 10 ns double-hit resolution. The higher counting accuracy, compared to the legacy system, will allow a more precise measurement of Luminosity and discrimination of Machine Induced Background.The modular nature of this hardware and firmware will allow to extend this system to other detectors.

Presented at *ELBA2018 14th Pisa meeting on advanced detectors*

Upgraded back-end electronics for the CMS Fast Beam Conditions Monitor

Nicolò Tosi[a], on behalf of the CMS Collaboration

[a] *Istituto Nazionale di Fisica Nucleare, I.N.F.N.-Sezione di Bologna, Viale B. Pichat 6/2, 40127 Bologna, Italy*

Abstract

In the CMS experiment, the Fast Beam Conditions Monitor (BCM1F) provides an online, bunch-by-bunch measurement of luminosity and machine induced background. The Beam Pickup Transformer (BPTX) provides a precise measurement of beam intensity and arrival time. Upgraded back-end electronics have been developed for the BCM1F, based on the μTCA standard. This system is slated to replace the current VME-based readout as well as the BPTX readout for the next LHC run.

Keywords: Front End, Trigger, DAQ and Data Management, CMS, BCM1F, Luminosity

1. Introduction

An upgraded back-end electronics has been installed for the BCM1F detector, in order to maintain its luminosity measurement performance in the increased pileup conditions of LHC Run 2. This system will provide better linearity by improving discrimination of closely spaced signal pulses.

2. Motivation

2.1. The detector

The BCM1F Detector [1] consists of four half rings, also referred to as C-shapes, installed on both sides of the CMS Interaction Point, at a distance of 1.8m, and a radius of 7cm. Each C-shape is equipped with six solid state sensors, with two pads per sensor and an area of a few square mm. Each pad is read out independently by a fast amplifier ASIC [2], for a total of 48 channels. The signal is extracted from the detector in analog form via optical fibers, by means of linear laser drivers and receivers placed in the service cavern. The current back-end is implemented with VME fixed threshold discriminators tuned to detect MIP signals, followed by a custom histogram unit board which stores hit counts per quarter of Bunch Crossing (6.25 ns).

2.2. The challenge

For the detector to be accurate across a wide range of luminosity values, it is important that the measured count rate is proportional to the particle flux. With the increased luminosity delivered by LHC in Run2, the current detector suffers from undercounting due to several effects, among which is the increased occupancy and chance of overlap between two pulses. This effect contributes to a decreased efficiency at higher single bunch instantaneous luminosity. These overlapping pulses cannot be resolved with a fixed threshold discriminator, and require the use of a pulse detection algorithm. This algorithm reduces the minimum separation required to discriminate two pulses, and also improves timing resolution by taking into account time walk introduced by different pulse sizes. The greater flexibility also allows to partially compensate for the loss of signal amplitude caused by radiation damage to the sensors and front-end electronics.

3. Upgraded Electronics

3.1. Hardware

The upgraded back-end electronics are based on commercial high speed flash ADCs that digitize the signal at 1200 MS/s, with 8 bit resolution. These are quad channel devices mounted on a commercial mezzanine card (FMC125 [3]), hosted on a CERN developed motherboard (GLIB [4]) in μTCA double width form factor. A total of twelve boards, mounted in two crates, is necessary to readout BCM1F. The digitized data is processed in real time on the motherboard in a Virtex 6 FPGA.

Email address: `nicolo.tosi@bo.infn.it` (Nicolò Tosi)

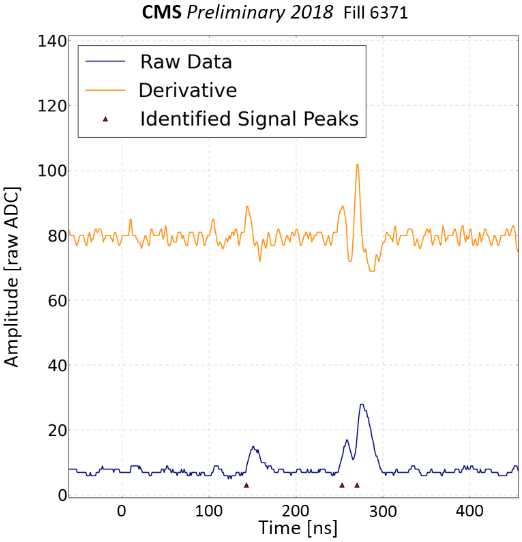

Figure 1: Example of raw data taken by the μTCA Back-End electronics from a BCM1F pCVD sensor. Several signal pulses corresponding to MIPs are visible. Shown superimposed (on an arbitrary scale) are the derivative as calculated by the pulse detection algorithm, as well as markers indicating the peaks that have been identified by the algorithm. The partially overlapping pulses have been correctly identified.

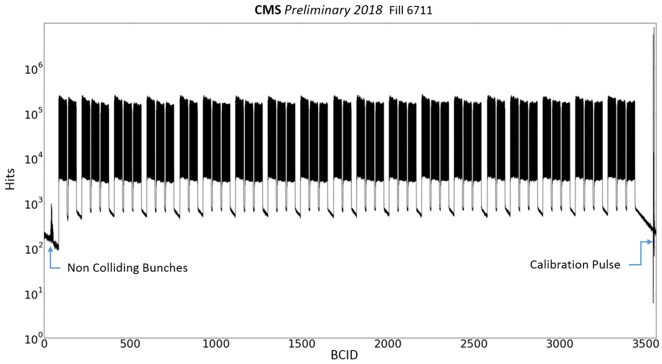

Figure 2: Raw occupancy histogram recorded by the μTCA back-end electronics from a BCM1F pCVD sensor. The data corresponds to approximately ten million orbits and is binned in six bins per bunch crossing. The train structure of the colliding bunches is visible, as well as a group of non colliding bunches, which create hits only from machine induced background.

3.2. *Signal processing*

A signal processing algorithm extracts pulse information such as amplitude and arrival time, which is then stored in histogram form, with a granularity of six bins per bunch crossing. The pulse detection algorithm implements as a first step a numerical differentiation of the signal. This allows to reject slow, occupancy dependent, baseline variations as well as low frequency noise. The derivative is implemented as a smooth noise-robust differentiator [5], which also includes a low pass filter for very high frequency noise, and is very efficiently implemented in FPGA architectures (Fig. 1). The second step is a search for a peak in the differentiated signal, requiring a minimum amplitude and isolation, which provides further noise suppression. The position of the derivative peak corresponds to the highest slope of the signal, and is chosen as the arrival time of the particle. A final step is the reconstruction of the signal amplitude through integration of the relevant part of the derivative signal.

3.3. *Readout*

The histograms are read out by software through the IPbus [6] protocol (also used for configuration) every second, providing a fine time granularity measurement of luminosity and machine induced background. One such histogram is shown in Fig. 2. Amplitude spectra, as well as a whole orbit waveform snapshot, are also read out periodically for sensor performance studies.

4. Application to BPTX

The BPTX is a device intended to measure precisely the arrival time of the two LHC beams, whose difference results in an offset of the collision region along the beam axis. It can also provide a measurement of the individual bunch charge, which complements the measurement performed by LHC instruments. Since BPTX only has two signals, the FMC125 digitizer can be configured to work in two-channel mode at 2.5GS/s, or single-channel at 5GS/s. The BPTX signal requires a different processing algorithm from the BCM1F, but the system can take advantage of the same hardware and of the modular nature of the firmware reusing all the compatible components. The data processing can make use of the signals periodic nature to enhance its measurement precision. By making use of online processing in the FPGA, a higher amount of data can be collected and averaged than is possible with the current software based analysis.

References

[1] A.A. Zagozdzinska, A.J. Bell, A.E. Dabrowski, M. Hempel, H.M. Henschel, O. Karacheban, D. Przyborowski, J.L. Leonard, M. Penno, K.T. Pozniak, M. Miraglia, W. Lange, W. Lohmann, V. Ryjov, A. Lokhovitskiy, D. Stickland, and R. Walsh. New Fast Beam Conditions Monitoring (BCM1F) system for CMS. *Journal of Instrumentation*, 11(01):C01088, 2016. URL `http://stacks.iop.org/1748-0221/11/i=01/a=C01088`.

[2] D. Przyborowski, J. Kaplon, and P. Rymaszewski. Design and Performance of the BCM1F Front End ASIC for the Beam Condition Monitoring System at the CMS Experiment. *IEEE Transactions on Nuclear Science*, 63:2300–2308, August 2016. doi: 10.1109/TNS.2016.2575781.

[3] Abaco Systems. Fmc-125. www.abaco.com/products/fmc125-fpga-mezzanine-card.

[4] P Vichoudis, J Andresen, S Baron, M Barros Marin, V Bobillier, J Chramowitz, S Haas, M Hansen, M Joos, L Lobato Pardavila, P Petit, A Prosser, and F Vasey. The Gigabit Link Interface Board (GLIB) ecosystem. *Journal of Instrumentation*, 8(03):C03012, 2013. URL `http://stacks.iop.org/1748-0221/8/i=03/a=C03012`.

[5] Pavel Holoborodko. Smooth noise robust differentiators. http://www.holoborodko.com/pavel/numerical-methods/numerical-derivative/smooth-low-noise-differentiators/, 2008.

[6] C. Ghabrous Larrea, K. Harder, D. Newbold, D. Sankey, A. Rose, A. Thea, and T. Williams. IPbus: a flexible Ethernet-based control system for xTCA hardware. *Journal of Instrumentation*, 10:C02019, February 2015. doi: 10.1088/1748-0221/10/02/C02019.